EFFECT OF FIELD DAMPING LAYER ON TWO STEP ABSORPTION OF QUANTUM DOTS SOLAR CELLS

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ABSTRACT

Multi-stacked InAs/AlGaAs quantum dot solar cells (QDSCs) introduced with field damping layers (FDL) which sustain the junction built-in potential have been studied. Without an external bias condition, the external quantum efficiency (EQE) of QD layers are reduced by introducing the thick FDL, because the carrier escape due to built-in electric field was suppressed. On the other hand, the photocurrent production due to two-step absorption is increased by the formation of flat-band QD structure for QDSC with thick FDL.

1. INTRODUCTION

QDs have attracted significant interest as a possible means of exploiting the sub-bandgap photons to generate additional photocurrent beyond that corresponding to the valence band (VB) to conduction band (CB) transitions in host material [1]. High conversion efficiencies exceeding the Shockley-Queisser limit theoretically are shown in such QD intermediate-band solar cells (IBSCs) [2].

We observed a photocurrent production at room temperature owing to two-step absorption of sub-bandgap photons for the multi-stacked InAs/GaNAs and InGaAs/GaAs QDSC [3,4]. However, the photocurrent production due to two-step photon absorption is still small. One of the reasons is that the carrier generated in QD layers can escape by electric-field, because QD layers are grown in a space charge region. The quasi-Fermi levels are not separated between IB and host material in this structure, thus decreasing the open-circuit voltage (V_{OC}) by introducing QD layers. This operation is essentially different from the concept of ideal IBSCs.

Martí *et al*. proposed to insert the *n*-type FDL between the *p*-type emitter layer and QDs layers in order to place the QDs layers in a flat-band region [5]. In this case, the FDL can sustain most of the *p-n* junction built-in potential. We focus on the effect of FDL on photovoltaic characteristics and two-step photon absorption of QDSC in this work.

2. EXPERIMENT

Two types of InAs/AlGaAs QDSCs were grown by molecular beam epitaxy. Figure 1 shows the schematic structure and energy band diagram of QDSCs fabricated in this study. The 10 stacked pairs of InAs QDs/$Al_{0.2}Ga_{0.8}As$ layer were grown in the intrinsic region. The QD layers were Si-doped directly during the self-assembling process of InAs growth [6]. The sheet density of Si doping was set to 2.7 x 10^{11} cm^{-2} per QD layer in order to dope approximately one Si atom per QD. In one type of cell, 100 nm thick FDL was inserted between p-emitter layer and multi-staked QD layers. The QDs are not located in a flat band region as shown in Fig. 1(b). For the other type, 400 nm thick FDL was grown resulting in a formation of flat band in the QDs region as show in Fig. 1(c).

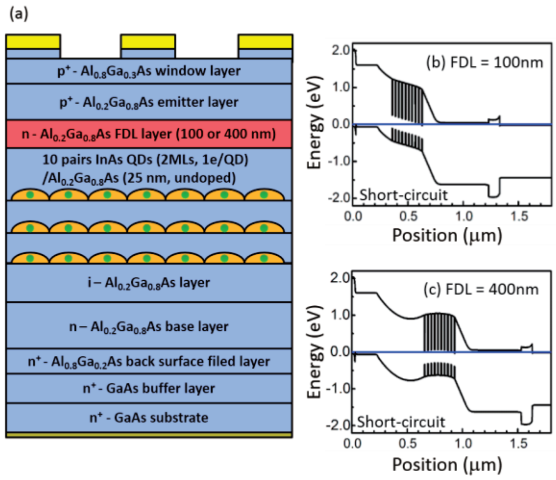

Fig. 1 (a) Schematic structure of InAs/AlGaAs QDSC fabricated in this work. Calculated band diagrams of the QDSCs with (b) 100 nm thick FDL and with (c) 400 nm thick FDL, respectively.

3. RESULTS AND DISCUSSION

Figure 2 plots the current-voltage (*J-V)* curves under 1-sun of AM 1.5 solar spectrum measured for 10-layer stacked InAs/AlGaAs QDSC with 100 and 400 nm thick FDL, respectively. The inset shows the PV parameters obtained from *J-V* curves of the each samples. The short-circuit current density (J_{SC}) for the QDSC with 400 nm thick FDL is higher than that of QDSC with 100 nm thick FDL. This is due to the fact that the total thickness is different between both samples by the thickness of FDL. On the other hand, the *FF* of 0.757 in the QDSC with 400 nm thick FDL is lower than that of QDSC with 100 nm thick FDL. For the QDSC introduced with thick FDL, the electric-field is excessively-suppressed in FDL as shown in Fig. 1(c). Consequently, the carrier collection efficiency decreases, and *FF* drops to a lower value.

Figure 3 shows (a) EQE spectra measured without an external bias and (b) the difference in EQE values, ΔEQE, taken with (EQE_{IR_on}) and without (EQE_{IR_off}) IR light illumination measured at room temperature. The IR light source was produced with IR filter that passes AM 1.5 sun light with the wavelength longer than 1064 nm. EQE response in the wavelength of longer than 750 nm is attributed to the contribution from 10 stacked InAs QD layers. The EQE of QD layers for the sample with 400 nm thick FDL is low compared to the sample with 100 nm thick FDL, because the carrier escape by electric field are suppressed. A clear photocurrent production due to two-step absorption is observed in the QDSC with 400 nm thick FDL, whereas no measurable photocurrent difference is found in the QDSC with 100 nm thick FDL. This result indicates that two-step absorption can be increased due to formation of a flat-band QD layers.

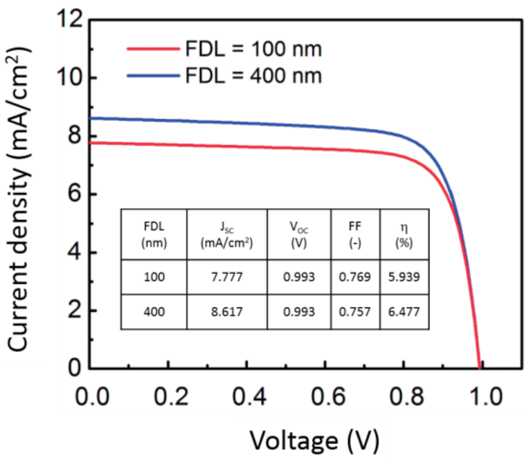

Fig. 2 *J-V* curves under AM 1.5 irradiation measured for InAs/AlGaAs QDSC with 100 and 400 nm thick FDLs, respectively. The inset shows PV parameters of each samples.

4. ACKNOWLEDGEMENT

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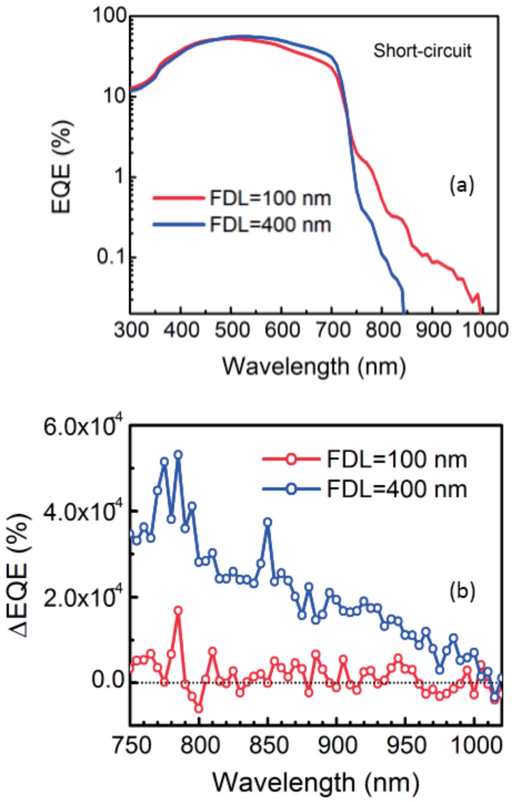

Fig. 3 (a) EQE spectra measured without external bias. (b) ΔEQE (= EQE_{IR_on} − EQE_{IR_off}) spectra measured at room temperature. The IR light source was produced with IR filter that passes AM 1.5 sun light with the wavelength longer than 1064 nm.

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